JACC: CARDIOVASCULAR IMAGING VOL. 4, NO. 5, 2011

ISSN 1936-878X/$36.00

PUBLISHED BY ELSEVIER INC.

DOI:10.1016/j.jcmg.2011.01.015

Prognostic Value of CT Angiography in Coronary Bypass Patients

Benjamin J. W. Chow, MD,*† Osman Ahmed, BSc,* Gary Small, MBChB,* Abdul-Aziz Alghamdi, MBBS,* Yeung Yam, BSc,* Li Chen, MSc,‡ George A. Wells, PhD‡

Ottawa, Ontario, Canada

OBJECTIVES We sought the incremental prognostic value of coronary computed tomography angiography (CTA) in coronary artery bypass graft (CABG) patients.

BACKGROUND Coronary CTA is a noninvasive and accurate tool for the detection of obstructive coronary artery disease, and coronary CTA appears to have prognostic value in patients without previous revascularization. However, the prognostic value of coronary CTA to predict major adverse cardiac events in CABG patients is unclear.

METHODS Consecutive CABG patients were prospectively enrolled and cardiac risk was calculated using the National Cholesterol Evaluation Program/Adult Treatment Panel III. Using the severity of native coronary artery disease and graft disease, the number of unprotected coronary territories (UCTs) (0, 1, 2, or 3) was calculated. Patients were followed for cardiac death and nonfatal myocardial infarction. All events were confirmed with death certificates or medical records and reviewed by a clinical events committee.

RESULTS Between February 2006 and March 2009, 250 consecutive patients were enrolled and followed for a mean of 20.8 ± 10.1 months. At follow-up, 23 patients (9.2%) had major adverse cardiac events (15 cardiac deaths and 8 nonfatal MI). The absence of UCTs conferred a good prognosis with an annual event rate of 2.4%. Conversely, patients with 1, 2, and 3 UCTs had annualized event rates of 5.8%, 11.1%, and 21.7%, respectively. Multivariable analysis showed that UCTs (hazard ratio: 2.08; 95% confidence interval: 1.40 to 3.10; $p < 0.001$) was a predictor of major adverse cardiac events when adjusted for clinical variables. Examining the receiver-operator characteristic curves, the area under the curve increased from 0.61 to 0.76 when UCTs was combined with clinical variables ($p = 0.001$).

CONCLUSIONS Assessing UCTs with coronary CTA appears to have prognostic value in CABG patients and is incremental to clinical variables. Coronary CTA appears to be a promising tool for risk stratification of CABG patients. Further multicenter studies using large CABG cohorts are needed to confirm our findings. (J Am Coll Cardiol Img 2011;4:496–502) © 2011 by the American College of Cardiology Foundation

From the *Division of Cardiology, University of Ottawa Heart Institute, Ottawa, Ontario, Canada; †Department of Radiology, The Ottawa Hospital, Ottawa, Ontario, Canada; and the ‡Cardiovascular Research Methods Centre, University of Ottawa Heart Institute, Ottawa, Ontario, Canada. This study was supported in part by the Imaging for Cardiovascular Therapeutics Project RE02-038 and the Canada Foundation for Innovation No. 11966. Dr. Chow is supported by CIHR New Investigator Award MSH-83718. He receives research support from GE Healthcare, Pfizer Inc., and AstraZeneca; fellowship training support from GE Healthcare; and educational support from TeraRecon Inc. The other authors have reported that they have no relationships to disclose.

Manuscript received November 10, 2010; revised manuscript received January 14, 2011; accepted January 18, 2011.

Coronary computed tomography angiography (CTA) is a noninvasive diagnostic tool useful for the detection of obstructive coronary artery disease (CAD) and the assessment of coronary artery bypass grafts (CABG) (1–13). Coronary CTA has prognostic value and predicts all-cause mortality and major adverse cardiac events (MACE) such as cardiac death and nonfatal myocardial infarction (MI) (14–19). However, previous studies have excluded patients with a history of coronary revascularization (14–19). To further support the utility of coronary CTA in patients with CABG, the prognostic value of 64-slice coronary CTA in this population requires further investigation.

See pages 492 and 503

Studies using invasive coronary angiography have demonstrated that the completeness of revascularization is an important predictor of outcome and that the number of arterial territories lacking a patent graft is a key determinant of mortality (20). Although coronary CTA can assess coronary and graft disease, its ability to assess the native arteries of CABG patients has been questioned (3,21). Thus, demonstrating the prognostic value of coronary CTA in the CABG population would further support its clinical use.

The objective of this prospective cohort study is to understand the potential incremental prognostic value of coronary CTA in CABG patients.

METHODS

Between February 2006 and March 2009, 269 consecutive CABG patients undergoing coronary CTA were prospectively enrolled in a Cardiac CTA Registry and were followed for all-cause death and MACE (cardiac death and nonfatal MI) (13,14). The study was approved by the Institutional Human Research Ethics Board, and all patients provided written informed consent.

Clinical predictors. A detailed medical history and laboratory results were recorded at the time of coronary CTA. Although a validated prognostic clinical model for CABG patients is lacking, age, sex, hypertension, and diabetes appear to be predictors of late cardiac events in CABG patients (22,23). Therefore, patients' age, sex, cardiac risk factors, and symptoms were used to estimate patient risk using the National Cholesterol Education Program/Adult Treatment Panel III (NCEP/ATP III) Guidelines and the Morise score (14,24,25).

Coronary CTA. Before image acquisition, metoprolol or diltiazem (oral and/or intravenous) was administered, targeting a heart rate of ≤65 beats/min, and nitroglycerin 0.8 mg was administered sublingually (14,26,27). A biphasic timing bolus (15 to 25 ml of contrast (Visipaque 320 or Omnipaque 350, GE Healthcare, Princeton, New Jersey; 40 ml of saline solution) was used (13,14). A triphasic protocol (100% contrast, 40%/60% contrast/saline solution [50 ml], and saline solution [40 ml]) was used to acquire the final dataset. The volume and rate of contrast were individualized according to scan time and patient body habitus (13,14).

Retrospective electrocardiogram-gated datasets were acquired with the GE Volume CT (GE Healthcare, Milwaukee, Wisconsin) (64 × 0.625-mm slice collimation, 350-ms gantry rotation, 400 to 800 mA, kilovolt peak = 120, and pitch of 0.16 to 0.24) (14). Images were reconstructed using a slice thickness of 0.625 mm with an increment of 0.4 mm using the cardiac phase(s) with the least amount of cardiac motion (13,14).

Coronary CTA image analysis. Images were post-processed using the GE Advantage Volume Share Workstation (GE Healthcare) and interpreted by expert observers blinded to all clinical data (14). A 4-point grading score (normal, mild [<50%], moderate [50% to 69%], severe [≥70%]) was used for the evaluation of native CAD and CABG (28). In segments that were unassessable, forced reading was performed, and readers provided their best educated guess. Cases with >5 unassessable segments were excluded from analysis. Significant stenoses were defined as left main ≥50% diameter stenosis, other native vessel stenosis ≥70%, or graft stenosis ≥70%.

Patients were categorized according to the number (0, 1, 2, or 3) of unprotected coronary territories (UCTs) (20). Each patient had 3 coronary territories, corresponding to each major epicardial artery (left anterior descending artery, circumflex artery or artery supplying the posterior descending artery [right coronary artery or circumflex artery]) and their corresponding branches (diagonal and marginal arteries). A coronary territory was deemed unprotected if: 1) an ungrafted native coronary artery had a significant stenosis; 2) a significant stenosis in the native artery was distal to the graft

ABBREVIATIONS AND ACRONYMS

CABG = coronary artery bypass graft

CAD = coronary artery disease

CTA = computed tomography angiography

MACE = major adverse cardiac event(s)

MI = myocardial infarction

NCEP/ATP = III = National Cholesterol Education Program/Adult Treatment Program III

UCT = unprotected coronary territory

JACC: CARDIOVASCULAR IMAGING, VOL. 4, NO. 5, 2011
MAY 2011:496–502

insertion; or 3) a native artery and its graft both had significant stenoses (20). The left main was assigned 2 coronary territories in right dominant system, but 3 coronary territories when left dominant. Similarly, the circumflex artery was assigned 2 territories when the native coronary system was left dominant.

Patient follow-up. Patient follow-up was performed (at 6-month intervals) by telephone interview by trained research staff blinded to all clinical data. All events were confirmed with death records, hospital records, or correspondence with treating physicians. A clinical events committee (blinded to the results of the coronary CTA) reviewed all events.

Outcome measures. The primary outcome measure was a composite of cardiac death and nonfatal MI. All deaths were reviewed and classified as cardiac or noncardiac. Deaths were considered cardiac when the primary cause of death was related to myocardial ischemia/infarction, heart failure or cardiac arrhythmia, and when a noncardiac cause of death could not be identified (29). Nonfatal MI was defined as myocardial ischemia resulting in abnormal cardiac biomarkers (>99th percentile of the upper normal limits) (30).

Statistical analysis. Statistical analyses were performed using SAS software version 9.2 (SAS Institute Inc., Cary, North Carolina), and statistical significance was defined as $p < 0.05$. Continuous variables were presented as means and SDs, and categorical variables were presented as frequencies with percentages.

The prognostic value of UCTs was assessed for univariable association as well as multivariable association with MACE. All unadjusted comparisons of cardiac events were performed using log-rank tests. For risk-adjusted analysis, a multivariable Cox proportional hazard model was used to assess the independent prognostic value of UCTs adjusted for clinical variables (NCEP/ATP III) and created adjusted survival curves. Model overfitting was considered, and the proportional hazards assumption was met. The incremental value of UCTs was calculated by defining the clinical variables model followed by the addition of UCTs. The area under receiver-operator characteristic curves (95% confidence intervals) was compared to evaluate the discrimination ability of UCTs over clinical variables to predict MACE.

RESULTS

Study population. Over an enrollment period of 37 months, 4,536 consecutive patients underwent coronary CTA with a total of 4,508 patients (99.4%) prospectively enrolled in the University of Ottawa Heart Institute Cardiac CTA Registry. Of these, 269 had previous CABG surgery and met the inclusion criteria for this study. A total of 10 patients were excluded from analysis for >5 unassessable segments. Follow-up was available for 250 patients (96.5%) with 9 patients lost to follow-up (Table 1). The baseline characteristics of the patients lost to follow-up were similar to those with follow-up, except those lost to follow-up were younger and were more likely to have atypical chest pain or dyspnea.

Univariable analysis of baseline characteristics with MACE. Univariable analysis of baseline characteristics is summarized in Table 2. Patients with

Table 1. Characteristics of Patients With Follow-Up (n = 250)

Mean follow-up, months	20.8 ± 10.1
Age, yrs	65.4 ± 9.5
Men	200 (80.0)
Body mass index, kg/m^2	29.5 ± 5.7
Cardiac risk factors	
Smoker/ex-smoker	175 (70.0)
Hypertension	157 (62.8)
Dyslipidemia	235 (94.0)
Diabetes	87 (34.8)
Family history of CAD	136 (54.4)
Indications for study	
Chest pain	150 (60.0)
Nonanginal chest pain	22 (8.8)
Atypical angina	29 (11.6)
Typical angina	99 (39.6)
Dyspnea	55 (22.0)
Morise score	14.9 ± 2.8
NCEP/ATP III risk	
Low risk	3 (1.2)
Intermediate risk	59 (23.6)
High risk	188 (75.2)
Unprotected coronary territories	
0	128 (51.2)
1	74 (29.6)
2	37 (14.8)
3	11 (4.4)
Left ventricular ejection fraction, %*	57.9 ± 15.1
Imaging parameters	
Imaging heart rate, beats/min	57.9 ± 6.9
Contrast infusion rate, ml/s	6.2 ± 0.9
Total contrast volume, ml	125.3 ± 20.4
Effective dose, mSv†	23.2 ± 5.2

Values are mean ± SD or n (%). *Left ventricular ejection fraction could only be accurately measured in 233 patients. †Effective dose (mSv) = dose length product × 0.014.
CAD = coronary artery disease; NCEP/ATP III = National Cholesterol Education Program/Adult Treatment Program III.

MACE were older, had a higher Morise score, and a greater proportion were in the NCEP/ATP III high-risk category.

UCTs and MACE. The rates of MACE increased with the increasing number of UCTs and were observed in a total of 3.9%, 9.5%, 16.2%, and 45.5% of patients with 0, 1, 2, and 3 UCTs, respectively (Table 3). The absence of UCTs conferred a good prognosis with an annual event rate of 2.4%. Conversely, patients with 1, 2, and 3 UCTs had annualized event rates of 5.8%, 11.1%, and 21.7%, respectively.

Risk-adjusted Cox models. For the risk-adjusted analysis, the NCEP/ATP III was used as the clinical variable because it combined age, sex, and cardiac risk factors into a single measure. A multivariable Cox model demonstrated that UCTs (hazard ratio: 2.08; 95% confidence interval: 1.40 to 3.10; $p < 0.001$), was an independent predictor for MACE adjusted for the clinical variables (Fig. 1, Table 4).

Incremental value analysis. The discrimination ability of UCTs over NCEP/ATP III was evaluated using receiver-operator characteristic curves (Fig. 2). The area under the curve for the clinical variable only was 0.61 (95% confidence interval: 0.56 to 0.66), with a significant increase to 0.76 (95% confidence interval: 0.66 to 0.86) when UCTs was added ($p = 0.001$).

Table 2. Univariable Analysis of Clinical Characteristics for MACE

	No MACE (n = 227)	MACE (n = 23)	Hazard Ratio (95% CI)	p Value
Age, yrs	64.9 ± 9.5	70.3 ± 8.9	1.06 (1.01–1.11)	0.012
Male	180 (79.3)	20 (87.0)	1.72 (0.51–5.78)	0.384
BMI, kg/m^2	29.6 ± 5.7	28.0 ± 4.8	0.94 (0.87–1.02)	0.159
Cardiac risk factors				
Diabetes	78 (34.4)	9 (39.1)	1.21 (0.52–2.80)	0.656
Dyslipidemia	213 (93.8)	22 (95.7)	2.07 (0.28–15.51)	0.479
Hypertension	142 (62.6)	15 (65.2)	1.09 (0.46–2.57)	0.846
Family history of CAD	121 (53.3)	15 (65.2)	1.75 (0.74–4.13)	0.205
Smoker/ex-smoker	156 (68.7)	19 (82.6)	2.13 (0.72–6.26)	0.170
Morise score	14.8 ± 3.4	16.1 ± 3.0	1.12 (0.99–1.28)	0.081
NCEP/ATP III risk			6.66 (0.92–48.35)	0.061
Low	3 (1.3)	0 (0.0)		
Intermediate	58 (25.6)	1 (4.3)		
High	166 (73.1)	22 (95.7)		

Values are mean ± SD or n (%), unless otherwise indicated.
BMI = body mass index; CI = confidence interval; MACE = major adverse cardiac events; other abbreviations as in Table 1.

DISCUSSION

To our knowledge, the prognostic value of coronary CTA in CABG patients has not been previously reported. The results of our study suggest that coronary CTA assessment of UCTs is of prognostic value and is incremental to clinical measures.

Prognostic value of coronary CTA. The diagnostic accuracy and prognostic value of coronary CTA have been well studied but have focused on patients with suspected CAD and those without a history of coronary revascularization (1,14–16,31,32). Because these studies excluded CABG patients, the prognostic value of coronary CTA in the CABG population is unknown.

Conversely, the prognostic value of invasive coronary angiography in CABG patients has been well studied. Liao et al. (20) developed a prognostic model for CABG patients and showed that the graft index and number of protected coronary territories predicted all-cause death. The ability to translate this model to coronary CTA is less certain. Because CABG patients typically have severe native CAD and coronary calcification, the diagnostic accuracy of coronary CTA may be suboptimal (3,21). Such a reduction in diagnostic accuracy may negatively affect the ability of coronary CTA to determine prognosis and limit its utility in the CABG population. Confirming the prognostic value of coronary CTA would support its potential use in patients with previous CABG.

Although more complex invasive coronary angiography models have significant prognostic power (20), our UCTs model appears to be feasible with coronary CTA and simple to adopt into clinical practice. A simple UCTs score (0, 1, 2, 3) predicts annual MACE (2.4%, 5.8%, 11.1%, and 21.7%, respectively).

Table 3. Number of UCTs and Adverse Cardiac Events (n = 250)

		MACE			
# of UCTs	*n*	Cardiac Death	Nonfatal MI	Cardiac Death, Nonfatal MI	Annual Event Rate, %
0	128	2 (1.6)	3 (2.3)	5 (3.9)	2.35
1	74	5 (6.8)	4 (5.4)	7 (9.5)	5.80
2	37	4 (10.8)	3 (8.1)	6 (16.2)	11.1
3	11	4 (36.4)	3 (27.3)	5 (45.5)	21.7
Log-rank p value		<0.001	0.003	<0.001	

Values are n (%).
MI = myocardial infarction; UCTs = unprotected coronary territories; other abbreviation as in Table 2.

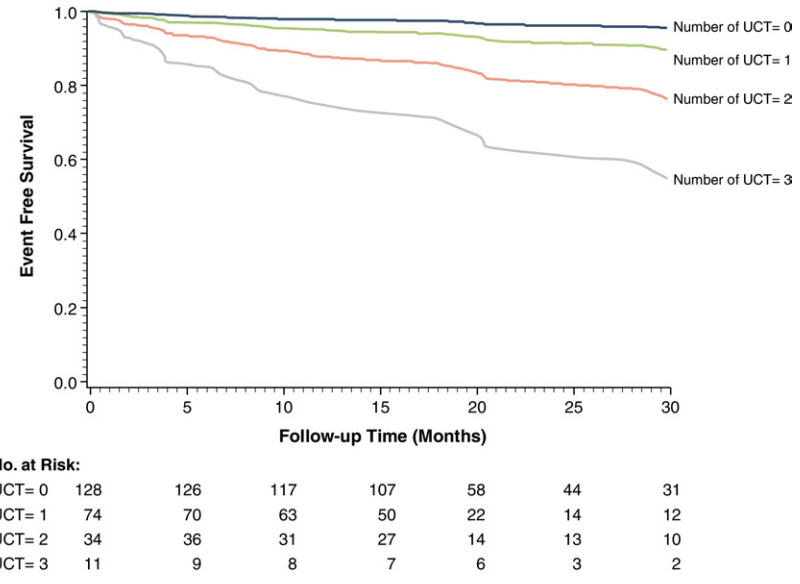

Figure 1. Risk-Adjusted Event-Free Survival

Risk-adjusted event-free (cardiac death or nonfatal myocardial infarction) survival according to the number of unprotected coronary territories (UCTs) (0 UCTs [**blue line**], 1 UCTs [**green line**]), 2 UCTs [**red line**], and 3 UCTs [**gray line**], $p < 0.001$).

Previous coronary CTA prognosis studies have used different outcome measures. Some have used all-cause mortality, whereas others have combined softer endpoints such as unstable angina and coronary revascularization (15–19). One strength of our study, although small, is the use of hard cardiac endpoints (cardiac death and nonfatal MI). Although all-cause mortality is an important and valuable outcome measure, coronary CTA alone cannot accurately predict deaths caused by cancer, sepsis, or trauma. Chow et al. (14) demonstrated that 59% of deaths in a low-risk coronary CTA population were noncardiac; therefore, using cardiac endpoints may often be preferred. Our results expand on previous literature by studying a novel population and demonstrating that coronary CTA may have merit beyond diagnosis and may be used to risk stratify symptomatic CABG patients.

Table 4. Cox Models for MACE

Models	Hazard Ratio (95% CI)	p Value
Clinical variables		
NCEP/ATP III	6.66 (0.92–48.35)	0.061
Clinical + UCTs		
NCEP/ATP III	4.81 (0.66–35.22)	0.122
Unprotected coronary territories	2.08 (1.40–3.10)	<0.001
0	1.0	—
1	2.57 (0.81–8.12)	0.108
2	3.57 (1.09–11.77)	0.036
3	10.89 (3.12–37.99)	<0.001

Abbreviations as in Tables 2 and 3.

Predictors of MACE in CABG patients. The NCEP/ATP III was initially designed and validated in patients without known CAD; therefore, its utility in the CABG population is unclear (25). Although the CABG population is traditionally considered at high risk of future cardiovascular events, each individual's risk may vary. Because studies have shown that CABG surgery reduces cardiac mortality (22), CABG patients may not be uniformly at high risk of cardiac events, especially when cardiac death is used as one of the outcome measures. Previous work has identified that age, sex, hypertension, and diabetes are clinical predictors of late cardiac events in CABG patients (22,23). Because the NCEP/ATP III combines these risk factors, it was selected as the primary clinical model for comparison.

It has been recognized that left ventricular ejection fraction has prognostic and incremental value over CAD severity (14). Although left ventricular ejection fraction measures were available for our population, our small sample size limited our ability to assess the incremental value of ejection fraction over UCTs and clinical predictors. Future studies

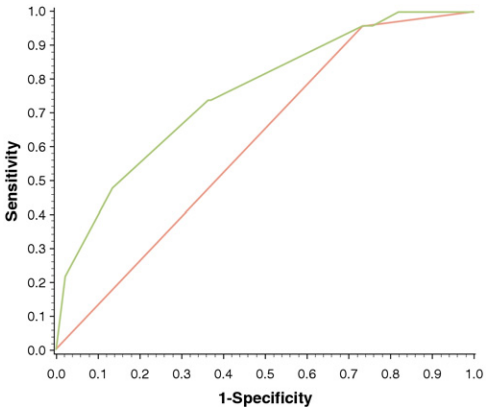

Figure 2. Receiver-Operator Characteristic Curves

Significant differences in the area under the receiver-operator characteristic curves confirm the incremental value of unprotected coronary territories (area under the curve: 0.76; 95% confidence interval: 0.66 to 0.86) **(green line)** over clinical variables (area under the curve: 0.61; 95% confidence interval: 0.56 to 0.66) **(red line)** ($p = 0.001$).

are needed to understand the incremental value of left ventricular ejection fraction in this patient population.

The estimated patient radiation dose in our study (23.2 ± 5.2 mSv) was higher than that in previous coronary CTA studies. This likely relates to the greater scan length needed to ensure coverage of bypass grafts. In addition, many of the patients were recruited before the availability of prospective electrocardiogram-gated acquisition at our institution. Understanding the potential harm of radiation exposure, the authors stress the importance of radiation reduction techniques and that such techniques should be used whenever possible.

Study limitations. This was a single-center, prospective study of patients referred for coronary CTA, and the results of our study may not necessarily be translatable to the general CABG population or to populations at other centers. Although prospectively enrolled, the CABG population was small with relatively few events, thus potentially subjecting our analysis to overfitting.

Patient follow-up in our study was excellent (96.5%) and similar to previous prognostic studies (33). However, the authors recognize that incomplete follow-up (n = 9) may result in the underreporting of MACE, which could affect our findings. In addition, the small numbers of MACE restricted our ability to assess the incremental value of left ventricular ejection fraction and arterial and venous grafts. Further multicenter studies using larger CABG cohorts with extended follow-up are required.

CONCLUSIONS

The assessment of native CAD, CABG, and UCTs with coronary CTA appears to have independent and incremental prognostic value over clinical predictors. Coronary CTA appears to be a promising tool for risk stratification of CABG patients. Further multicenter studies using large CABG cohorts are needed to confirm our findings.

Acknowledgments

The authors extend their gratitude to Kathryn Calladine, Nancy Chow, Debbie Gauthier, Patricia Grant, Sandina Jamieson, and Richard Tessier for their expertise and dedication to cardiac research.

Reprint requests and correspondence: Dr. Benjamin Chow, University of Ottawa Heart Institute, 40 Ruskin Street, Ottawa, Ontario K1Y 4W7, Canada. *E-mail: bchow@ottawaheart.ca.*

REFERENCES

1. Weustink AC, Nieman K, Pugliese F, et al. Diagnostic accuracy of computed tomography angiography in patients after bypass grafting: comparison with invasive coronary angiography. J Am Coll Cardiol Img 2009;2:816–24.
2. Malagutti P, Nieman K, Meijboom WB, et al. Use of 64-slice CT in symptomatic patients after coronary bypass surgery: evaluation of grafts and coronary arteries. Eur Heart J 2007;28:1879–85.
3. Raymonda L, Jimmy L, Gregory K, Gervais W, Kenneth N, Kheng-Thye H. Comprehensive noninvasive evaluation of bypass grafts and native coronary arteries in patients after coronary bypass surgery: accuracy of 64-slice multidetector computed tomography compared to invasive coronary angiography. J Cardiovasc Med 2010; 2:81–90.
4. Hoffmann MH, Shi H, Schmitz BL, et al. Noninvasive coronary angiography with multislice computed tomography. JAMA 2005;293: 2471–8.
5. Hoffmann U, Nagurney JT, Moselewski F, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation 2006;114: 2251–60.
6. Ropers D, Rixe J, Anders K, et al. Usefulness of multidetector row spiral computed tomography with 64- × 0.6-mm collimation and 330-ms rotation for the noninvasive detection of significant coronary artery stenoses. Am J Cardiol 2006;97:343–8.
7. Leber AW, Knez A, von Ziegler F, et al. Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 2005; 46:147–54.

8. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 2005; 46:552–7.
9. Mollet NR, Cademartiri F, van Mieghem CAG, et al. High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. Circulation 2005; 112:2318–23.
10. Chow BJ, Hoffmann U, Nieman K. Computed tomographic coronary angiography: An alternative to invasive coronary angiography. Can J Cardiol 2005;21:933–40.
11. Beanlands RSB, Chow BJW, Dick A, et al. CCS/CAR/CANM/CNCS/CanSCMR joint position statement on advanced noninvasive cardiac imaging using positron emission tomography, magnetic resonance imaging and multidetector computed tomographic angiography in the diagnosis and evaluation of ischemic heart disease–executive summary. Can J Cardiol 2007;23:107–19.
12. Schuijf JD, Bax JJ, Shaw LJ, et al. Meta-analysis of comparative diagnostic performance of magnetic resonance imaging and multislice computed tomography for noninvasive coronary angiography. Am Heart J 2006;151:404–11.
13. Chow BJW, Abraham A, Wells GA, et al. Diagnostic accuracy and impact of computed tomographic coronary angiography on utilization of invasive coronary angiography. Circ Cardiovasc Imaging 2009;2:16–23.
14. Chow BJW, Wells GA, Chen L, et al. Prognostic value of 64-slice cardiac computed tomography: Severity of coronary artery disease, coronary atherosclerosis and left ventricular ejection fraction. J Am Coll Cardiol 2010; 55:1017–28.
15. Min JK, Shaw LJ, Devereux RB, et al. Prognostic value of multidetector coronary computed tomographic angiography for prediction of all-cause mortality. J Am Coll Cardiol 2007; 50:1161–70.
16. Ostrom MP, Gopal A, Ahmadi N, et al. Mortality incidence and the severity of coronary atherosclerosis assessed by computed tomography angiography. J Am Coll Cardiol 2008;52:1335–43.
17. Gilard M, Le Gal G, Cornily JC, et al. Midterm prognosis of patients with suspected coronary artery disease and normal multislice computed tomographic findings: A prospective management outcome study. Arch Intern Med 2007;167:1686–9.
18. Pundziute G, Schuijf JD, Jukema JW, et al. Prognostic value of multislice computed tomography coronary angiography in patients with known or suspected coronary artery disease. J Am Coll Cardiol 2007;49:62–70.
19. Gaemperli O, Valenta I, Schepis T, et al. Coronary 64-slice CT angiography predicts outcome in patients with known or suspected coronary artery disease. Eur Radiol 2008;18:1162–73.
20. Liao L, Kong DF, Shaw LK, et al. A new anatomic score for prognosis after cardiac catheterization in patients with previous bypass surgery. J Am Coll Cardiol 2005;46:1684–92.
21. Nieman K, Pattynama PM, Rensing BJ, van Geuns RJ, de Feyter PJ. Evaluation of patients after coronary artery bypass surgery: CT angiographic assessment of grafts and coronary arteries. Radiology 2003;229:749–56.
22. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA 2004 guideline update for coronary artery bypass graft surgery: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1999 Guidelines for Coronary Artery Bypass Graft Surgery). J Am Coll Cardiol 2004;44: e213–310.
23. Thourani VH, Weintraub WS, Stein B, et al. Influence of diabetes mellitus on early and late outcome after coronary artery bypass grafting. Ann Thorac Surg 1999;67:1045–52.
24. Morise AP, Haddad J, Beckner D. Development and validation of a clinical score to estimate the probability of coronary artery disease in men and women presenting with suspected coronary disease. Am J Med 1997;102:350–6.
25. National Cholesterol Education Program Expert Pane on Detection. Final Report Washington, DC: National Institutes of Health, 2009.
26. Abbara S, Arbab-Zadeh A, Callister TQ, et al. SCCT guidelines for performance of coronary computed tomographic angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee. J Cardiovasc Comput Tomogr 2009;3:190–204.
27. Chun EJ, Lee W, Choi YH, et al. Effects of nitroglycerin on the diagnostic accuracy of electrocardiogram-gated coronary computed tomography angiography. J Comput Assist Tomogr 2008;32:86–92.
28. Hoffmann U, Moselewski F, Cury RC, et al. Predictive value of 16-slice multidetector spiral computed tomography to detect significant obstructive coronary artery disease in patients at high risk for coronary artery disease: patient- versus segment-based analysis. Circulation 2004;110:2638–43.
29. Radford MJ. Arnold JM, Bennett SJ, et al. ACC/AHA key data elements and definitions for measuring the clinical management and outcomes of patients with chronic heart failure: a report of the ACC/AHA Task Force on Clinical Data Standards (Heart Failure Data Standards Writing Committee). J Am Coll Cardiol 2005; 46:1179–207.
30. Thygesen K, Alpert JS, White HD, on behalf of the Joint ESC/ACCF/AHA/WHF Task Force for the Redefinition of Myocardial Infarction. Universal definition of myocardial infarction. J Am Coll Cardiol 2009; 50:2173–95.
31. Auguadro C, Manfredi M, Scalise F, et al. Multislice computed tomography for the evaluation of coronary bypass grafts and native coronary arteries: comparison with traditional angiography. J Cardiovasc Med 2009;10:454–60.
32. Gopal A, Nasir K, Ahmadi N, et al. Cardiac computed tomographic angiography in an outpatient setting: an analysis of clinical outcomes over a 40-month period. J Cardiovasc Comput Tomogr 2009;3:90–5.
33. Hachamovitch R, Berman DS, Shaw LJ, et al. Incremental prognostic value of myocardial perfusion single photon emission computed tomography for the prediction of cardiac death: differential stratification for risk of cardiac death and myocardial infarction. Circulation 1998;97:535–43.

Key Words: cardiac death ■ computed tomography ■ coronary angiography ■ coronary artery bypass graft ■ major adverse cardiac events ■ myocardial infarction ■ prognosis.